MEASURING AND MODELING OF SHRINKAGE CHARACTERISTIC NATURAL SOIL IN KUANTAN PAHANG

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ABSTRACT

One of uses of clayey soil in engineering is as liner material. Natural soil containing clay minerals are often used as cheaper alternatives. Clayey soil undergoes shrinkage during drying with water content changes. Water content changes during wetting undergo swelling. Shrinkage cracks are major problem in many engineering construction. Liners that undergo excessive shrinkage behaviour will caused the formation of cracks and create problems to the environment and human safety. In this study, the shrinkage behaviour of KB soil was determined during drying under zero applied stress. The volumes of soil specimens prepared at different water contents were measured using wax method. Additionally, the shrinkage curves were established using Kea and Gea model. The shrinkage curves enabled the determination of shrinkage limit of the soil as well as void ratios at consistency limits. The wax method was found to be useful in establishing the entire shrinkage characteristics of soils during the drying process. Similarly, the uses of parametric models provide continuous shrinkage curves with some limitations.

ABSTRAK

Salah satu penggunaan tanah liat dalam bidang kejuruteraan adalah sebagai bahan pelapik. Tanah natural yang mengandungi mineral tanah liat sering digunakan sebagai alternatif yang lebih murah. Tanah liat mengalami pengecutan semasa pengeringan dengan perubahan kandungan air. Tanah akan mejadi bengkak apabila berlakunya perubahan kandungan air. Masalah utama dalam bidang kejuruteraan adalah retak pengecutan. Keadaan pengecutan yang berlebihan dalam pelapik akan menyebabkan pembentukkan retak dan menimbulakn masalah kepada alam sekitar dan keselamatan manusia. Dalam kajian ini, tingkah laku pengecutan tanah KB telah ditentukan semasa pengeringan di bawah tekanan sifar . Jumlah spesimen tanah yang disediakan pada kandungan air yang berbeza telah diukur dengan menggunakan kaedah lilin. Selain itu, lengkung pengecutan telah dihasilkan dengan menggunakan model Kea dan Gea. Lengkung pengecutan membolehkan had pengecutan tanah serta nisbah udara pada had yang konsisten di tentukan. Kaedah lilin telah didapati berguna dalam mewujudkan ciri-ciri pengecutan seluruh tanah semasa proses pengeringan. Begitu juga, penggunaan model parametrik menghasilkan lengkung pengecutan dengan beberapa batasan.

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β	-	Slope parameter depending on the air entry value
e	-	Void ratio
e_0	-	Initial void ratio
e_{SL}	-	Void ratio at shrinkage limit
e_{LL}	-	Void ratio at liquid limit
e_{PL}	-	Void ratio at plastic limit
G_s	-	Specific Gravity
M_1	-	Mass of the soil pat in the dish at the beginning of the test
M_2	-	Mass of the dry soil pat
M_0	-	Weight of sample oven-dry soil in gram
M_A	-	Weight of density bottle filled with water
M_B	-	Weight of density bottle filled with water and soil.
m_s	-	Mass of dry soil pat
m_d	-	Mass of dry soil pat and shrinkage dish
m	-	Mass of shrinkage dish
m_w	-	Mass of the wet soil and shrinkage dish
m_{sxa}	-	The mass of the wax-coated pat in air
m_{sxw}	-	The mass in water of the dry soil pat and wax
m_x	-	Mass of wax
m_s	-	Mass of soil before wax
n	-	Porosity
ρ_x	-	Density of wax
ρ_s	-	Density of soil
ρ_d	-	dry density

v_w	-	Volume of water
v_s	-	Volume of soil
v_x	-	Volume of wax
v_v	-	Volume of void
v_s	-	Volume of solid
V_w	-	Volume of water
V_a	-	Volume
V_s	-	Volume of solid
w_i	-	Initial moisture content
w	-	Water content
w_w	-	Weight of water
w_s	-	Weight of solid
Δw	-	Change in moisture content
ϑ_B	-	The moisture ratio at air entry
ϑ	-	Void Ratio
φ	-	The slope of saturation line
γ_w	-	Unit weight of water

LIST OF ABBREVIATION

KB	-	Kuantan Brick
AASHTO	-	American Association of State Highway and Transportation Officials.
USCS	-	Unified Soil Classification System
ASTM	-	American Society for Testing and Materials
PI	-	Plastic index
PL	-	Plastic Limit
LL	-	Liquid Limit
SL	-	Shrinkage Limit
AEV	-	Air Entry Value
UMP	-	Universiti Malaysia Pahang

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Clayey soils undergo shrinkage during water content changes. Shrinkage cracks are major problem in many engineering applications such as geotechnical engineering, mining engineering, agricultural engineering, and material engineering (Costa &Kodikara, 2007). One of the uses of clayey soil in engineering is as liners. The purpose of liners is to minimize or eliminate leakage of contaminants into groundwater (Bagchi, 2004). All municipal waste is placed at landfill, to avoid the leakage into groundwater; the liner must be able to retained water capacity (Bagchi, 2004). If the liner undergo cracks it create problem to environment and human safety. Owning to the significant importance of the problem, shrinkage characteristic has gained the attraction to many researchers (Kodikara et al., 2000; Costa & Kodikara, 2007; Peron et al., 2007) during the last couple of decades.

Clay soils have the ability to change in volume in response to changes in its water content; it is shrink when water content decreases and swells when it increases (Bhuvaneshwari et al, 2010). The volume change behavior of clayey soil causes big problem if the cracks happen in liner and allow the contaminant leakage into groundwater.

In order to measure the volume of shrinkage behavior, the laboratory tests are usually conducted involving volume measurement of soils. Basically, volumetric shrinkage can be measured by using mercury method and clod test, (Cornelis et al, 2006). However, these methods are time consuming, tedious and prone to errors. The use of paraffin wax in determining the void ratio at shrinkage limit of soils has been shown to be useful in measuring water content–void ratio relationships (ASTM D4943, 2008). Similarly, the method can be used to measure the void ratio of soils at different water content.

Studies in the past showed that the changes in the water content and void ratio of soils can be measured using parametric models, (Cornelis et al, 2006). To model water and solute transport in the soil, a continuous shrinkage characteristic curve is required, rather than a set of discrete experimental data pairs that can be obtained experimentally, (Cornelis et al, 2006).Several properties of soil such as specific gravity and water content has been successfully been used to establish a continuous shrinkage curve for given soil (Cornelis et al., 2006) In this study, the shrinkage curve was established using wax method. Furthermore, two different parametric models are also used to establish the shrinkage curve of the soil used in this study. The model that has been chosen is proposed by Giráldez et al. (1983) – Gea model and Kim et al. (1992) – Kea model.

The aim of this study is to measure the shrinkage characteristic of clay soil by using wax method and compare the result obtain from Gea model and Kea model.

1.2 PROBLEM STATEMENT

The problem related with shrinkage and swelling is well known in geotechnical problems and has been studied and researched by many geotechnical engineers for many decades (Abdelmalak, 2007). Clayey soils are well known with the ability to the water retention capacity, because of that, clay is choosing to be liner. It is important to study about the desiccation induced shrinkage cracks behavior because cracks are major unwanted problem in liner. The volume measurement was conducted to establish the soil shrinkage characteristic curve by using wax method in laboratory. But there is a lot of problem when using the laboratory test such as time consuming, errors and result is not accurate due to the others factor happen while doing test. Due to this statement, the two models that is Gea and Kea model was chose to determine the shrinkage characteristic by using equation. Several models that can be fitted to a set of discrete data pairs include polynomial models (Giràldez et al., 1983), and sigmoid model (Kim et al. (1992)). Since this model can simply to get the various data point compare to the experimental data point for this soil, it will helpful in time management to establish the result.

1.3 RESEARCH OBJECTIVES

The objectives of this study are:

i. to experimentally establish the shrinkage characteristic of clay soil by using wax method.
ii. to model the shrinkage curve using currently available shrinkage models – Gea and Kea model.

1.4 SCOPE AND LIMITATION

The shrinkage behavior of Kuantan natural soil from initially saturated slurried condition under zero applied stress using wax method. Multiple specimens were prepared and the volumes of specimens at different water contents were measured to establish the entire shrinkage path. Two shrinkage models are then used (i.e. Gea model and Kea model) and compared to the experimental shrinkage curve obtained from wax tests.

1.5 SIGNIFICANT

The shrinkage curve of KB soil may be established using parametric models, thus hinder the use of multiple duplicated specimens.

1.6 THESIS OVERVIEW

This thesis is divided into five consecutive chapters. The summary of each chapters are represented in the following manner:

Chapter II presents the literature review about landfill clay liner, clay soil, volume measurement methods used in measuring shrinkage, and currently available model for establish soil shrinkage characteristic curve.

CHAPTER III presents the physical and mineralogical properties of the soil used and methodology in establishing the shrinkage characteristic by using wax method.

CHAPTER IV presents the analysis and result obtained from this study. The results of soil properties determined, such as atterberg limit, specific gravity, particle size distribution, and x-ray diffraction method are presented first. Followed by The soil shrinkage characteristic curve are established experimentally and by using models. The void ratio at shrinkage limit, liquid limit, and plastic limit are also presented in this chapter.

CHAPTER V summarizes the main conclusion of this study

CHAPTER II

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents the literature review based on the study conducted. Section 2.2 present the general usage of clay in application in engineering followed by the section 2.3 reviews about the purpose of landfill , section 2.3.1 described about liner material that used in landfills design, section 2.3.2 present the clay liner material and the characteristic of clay liner used for landfill, followed by the section 2.4 present about the clay particle, section 2.5 present about the shrinkage of clays , the swelling of clay was present in section 2.6, section 2.7 present about soil properties of the soils, section 2.7.1 present about the atterberg limits which is liquid limit, plastic limit and shrinkage limit, section 2.8 present about volume measurement methods followed to the section 2.8.1 present about the wax method, section 2.9 and 2.10 present about the models used for this study which is Gea and Kea model.

2.2 GENERAL USAGE OF CLAY

Clayey soils undergo shrinkage during water content decrease, shrinkage of clay are major unwanted problem in many engineering application including geotechnical engineering, agricultural engineering, mining engineering, and material engineering, (Kodikara & Costa, 2009). Clayey soil are significant in many application in engineering, one of them is usage for landfill liner. Besides that, clayey soil is widely used for lining hazardous waste landfills and the main purpose of landfill liner is to minimize the contaminant into groundwater (Bagchi, 2004)

2.3 LANDFILLS

The landfills is design to minimum the possible contamination of soil, groundwater, and surface water that may occur as leachate produced by water or liquid wastes moving into, through and out of the landfill migrates into adjacent areas. To satisfy the design criteria, the clay liner are used or synthetic membrane or both and a leachate collection system is installed, (Bagchi, 2004).

Theoretically, the leakage through the base of a containment landfill is unavoidable, but it can be reduced. Usually clay or synthetic material is used in lining the landfill. Linear material is select based on the type of waste and landfill operation. The liner must be well-suited with leachate, (Bagchi, 2004).

2.3.1 Liner Materials

There are various type of materials used for landfill liner such as clayey soil, synthetic membranes or other artificially manufactured materials, and amended soil or other mixtures, (Bagchi, 2004). Every types of liner have advantages and disadvantages must be considered while choosing the landfill liner. The factor that must be considered are cost, material specifications, quality control test and specifications, minimum allowable thickness of the liner.

The function of landfill liners is to minimize the leakage of contaminants into groundwater. The contaminants may content the dangerous chemical or may affect the groundwater.

2.3.2 Clay Liner

The types of liner may be different according the types of waste; society produces many different solid wastes that pose different threats to environment and community health. Clayey soil is widely used for landfill liner. Liner may be described as single, composite, or double liners, (Hughes et al, 2005).

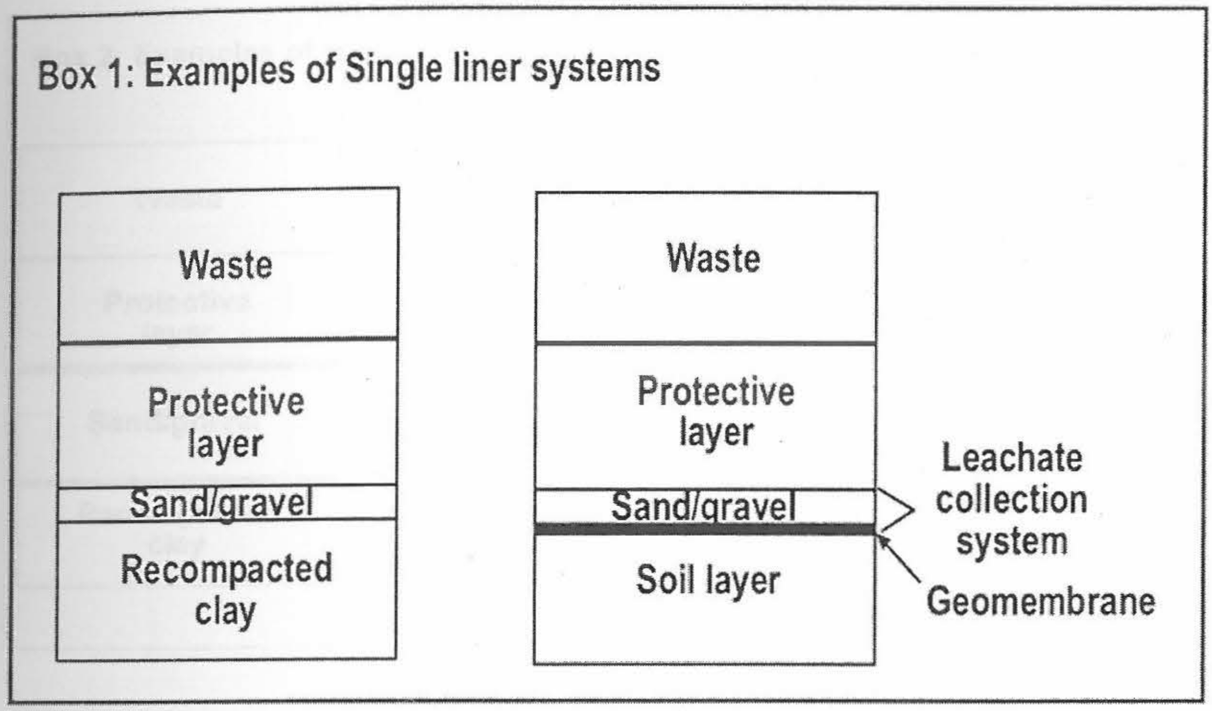

Figure 2.1: Example of single liner system

Figure 2.1 show example of single liner system. Single liner system is sometimes used in landfills. This landfill is not constructed to contain any paint, liquid tar, municipal garbage, or treated lumber; single liner system is usually adequate to protect the environment. The advantages of this system are it cheaper to dispose of construction materials and cheaper to build and maintain than others landfill, (Hughes et al, 2005).

Figure 2.2 shows that, a composite liner consist of a geomembrane in combination with a clay liner. The advantages of this types is more effective at limiting leachate migration into the subsoil than either a clay liner or a single geomembrane layer, (Hughes et al, 2005).

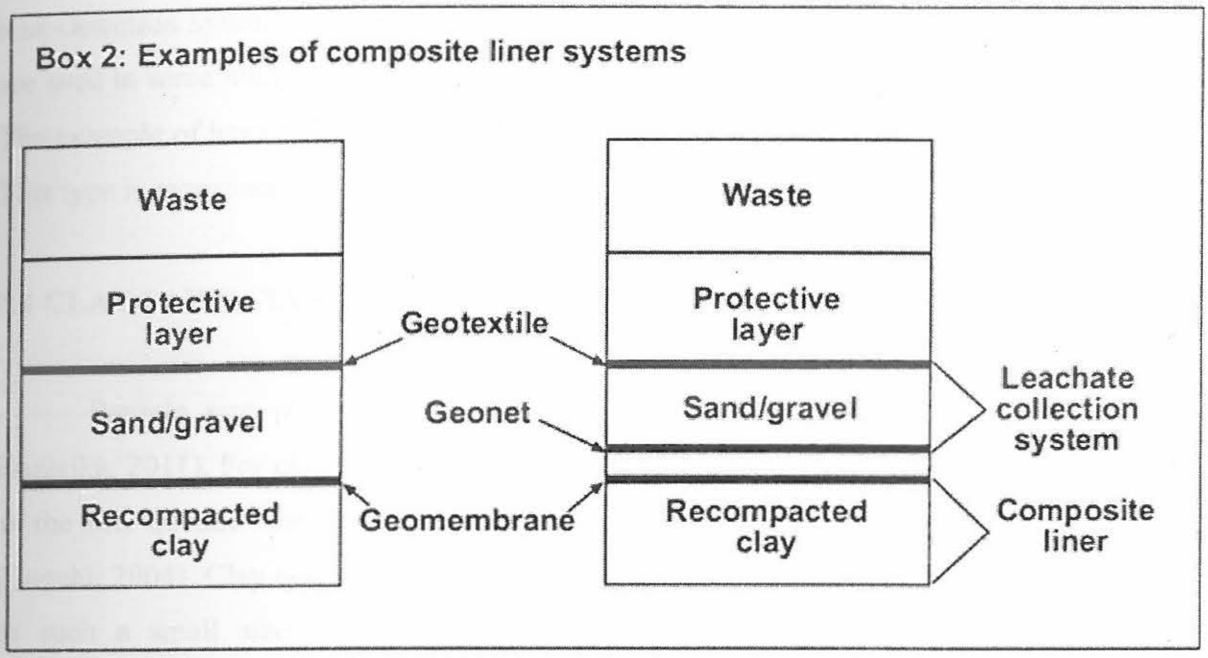

Figure 2.2: Example of composite liner system

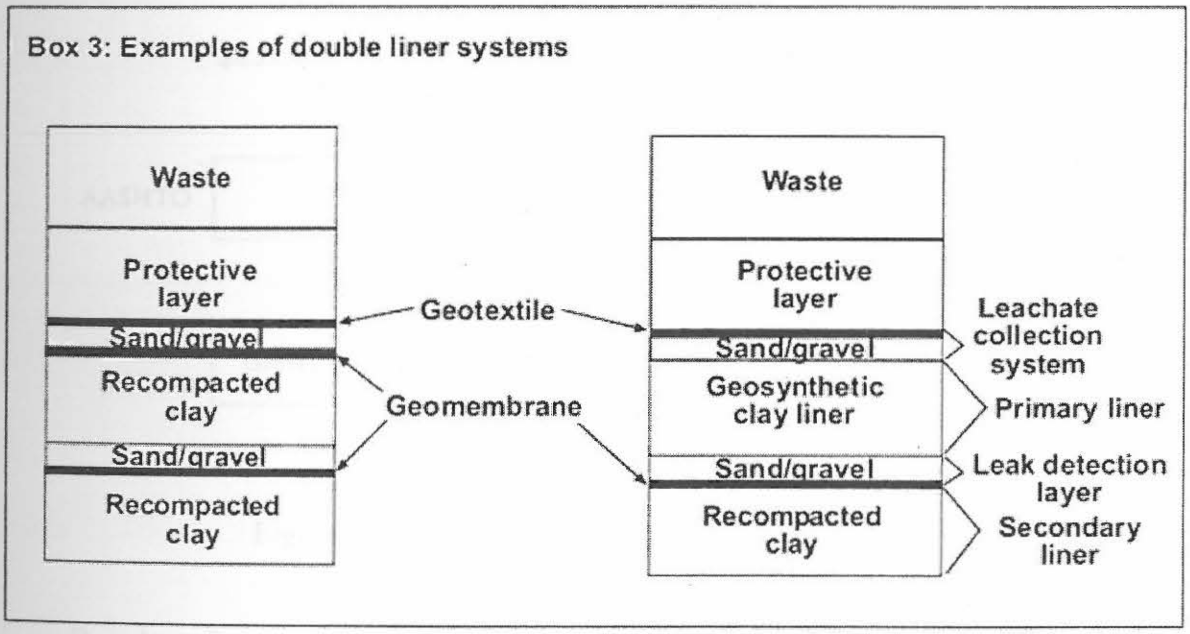

Figure 2.3: Example of double liner systems

Based on the figure 2.3 above a double liner consist of either two single liners, two composite liners, or a single and a composite liner. The upper (primary liner usually functions to collect leachate, while the lower (secondary) liner acts as a leak-detection system and backup to the primary liner. The advantages of this type are used in some municipal solid waste landfills and in all hazardous waste landfills. The example of hazardous waste is once were ignitable, corrosive, reactive, or toxic. This type is more securing compare to others types, (Hughes et al, 2005).

2.4 CLAY PARTICLES

Particle size plays a main role in distinguishing soil type (Ishibashi & Hazarika, 2011). For clay the particles equal to or finer than 0.002 mm (or 2 μm) or as the soil fraction that has particles equal to or finer than 0.005 mm (or 5 μm), (Bagchi, 2004). Clay needs extraordinary attention because of its small particle size. In such a small size, electrical interactive forces become more significant as compared to the physical frictional interactive forces in the case of larger grain soils include of sand and gravel, (Ishibashi & Hazarika, 2011).

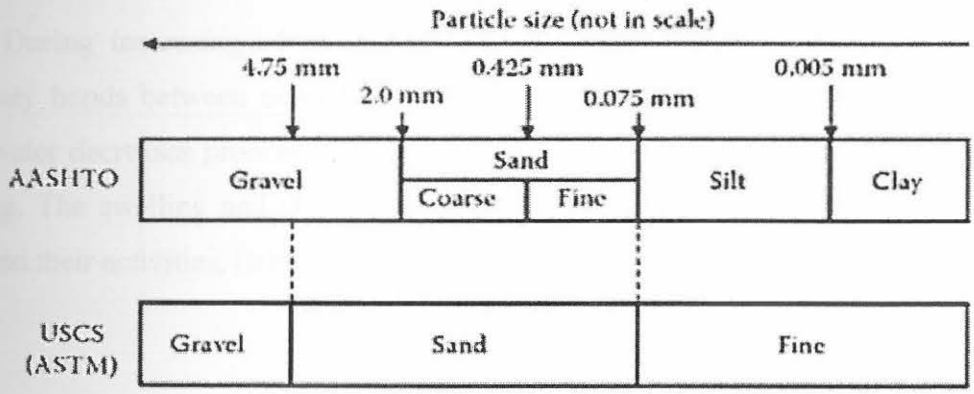

Figure 2.4: Soil's Names with grain sizes.

Based on figure 2.4 shown those name with ranges of grain size. The grain size is different based on the standards. Two mm in AASHTO or 4.75mm in USCS (Unified Soil Classification System) or in ASTM Soil Classification System are the boundary particle size between gravel and sand. 0.075 mm is the boundary between sand and silt in both standards and 5μm is the one between silt and clay in AASHTO. Materials that are finer than 75μm are called fine in USCS (ASTM). In some others standard such in British Soil classification (BS8004, 1986), 2 μm is used as the boundary between silt and clay, (Ishibashi & Hazarika, 2011)

2.5 SHRINKAGE OF CLAYS

Water content in clays always changes in accordance with the natural environment (i.e changes in relative humidity and temperature or soil suction) (Gens, 2010). Swelling and shrinkage of clays changes when water content changes. The volume changes depend on the amount of minerals contained within clay, types of clay and the characterized by their magnitude and geometry, (Cornelis et al, 2006). Excessive shrinkage would result in the formation of shrinkage cracks, (Cornelis et al, 2006). One the other hand, when clay contains a great deal of water, the clay will expand and swelling occurs, (Ishibashi & Hazarika, 2011).

2.6 SWELLING OF CLAYS

During increasing of water content, the clay swells mainly due to weak secondary bonds between exposed OH^- (Ishibashi & Hazarika, 2011),. Otherwise, when water decreases process of shrink happen due to the reversed phenomenon of swelling. The swelling and shrinkage potentials are closely related to the types of clays and their activities, (Ishibashi & Hazarika, 2011)

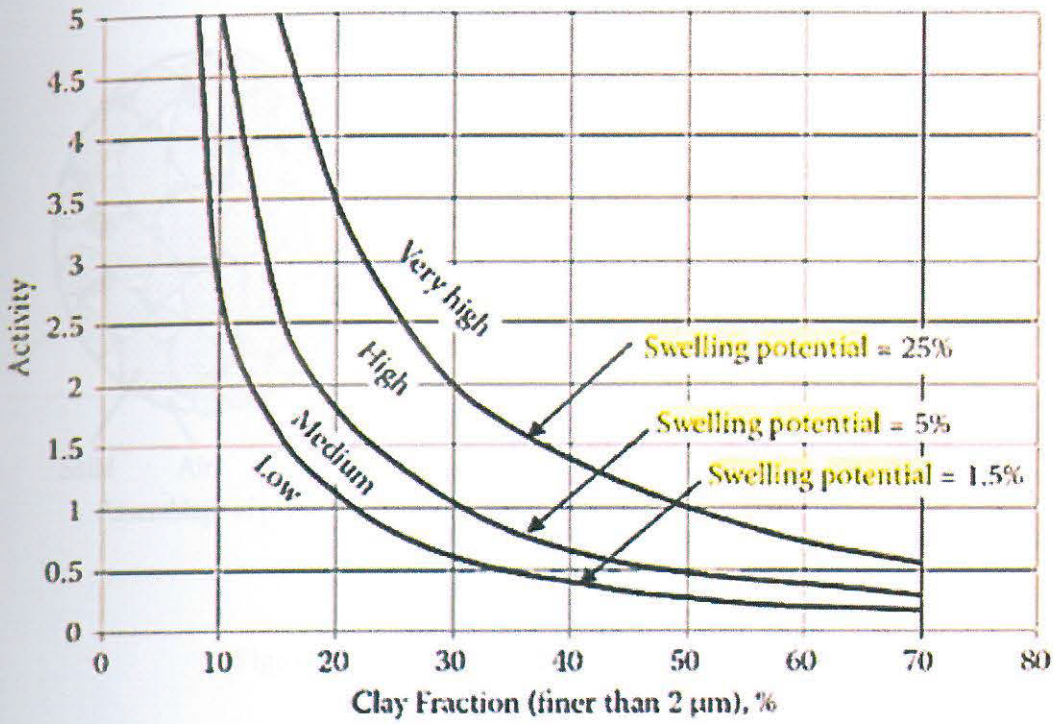

Figure 2.5: Classification chart for swelling potential.

Source: (Woodward & Lundgreen, 1962)

Figure 2.5 shows that classification chart for swelling potential. The higher swelling occurred for soil containing higher amount of clay fraction. Based on the chart above, the use of the chart is give guideline in classifying a soil for a potential swelling by simple knowing the parameters of the clay such as liquid limit, plastic limit and clay fraction.

2.7 SOIL PROPERTIES

According to the Ishibashi and Hazarika, soil can be defined as an assemblage of nonmetallic solid particles (mineral grains), and it is consist of three phases: solid, liguid (water), and gas (air).

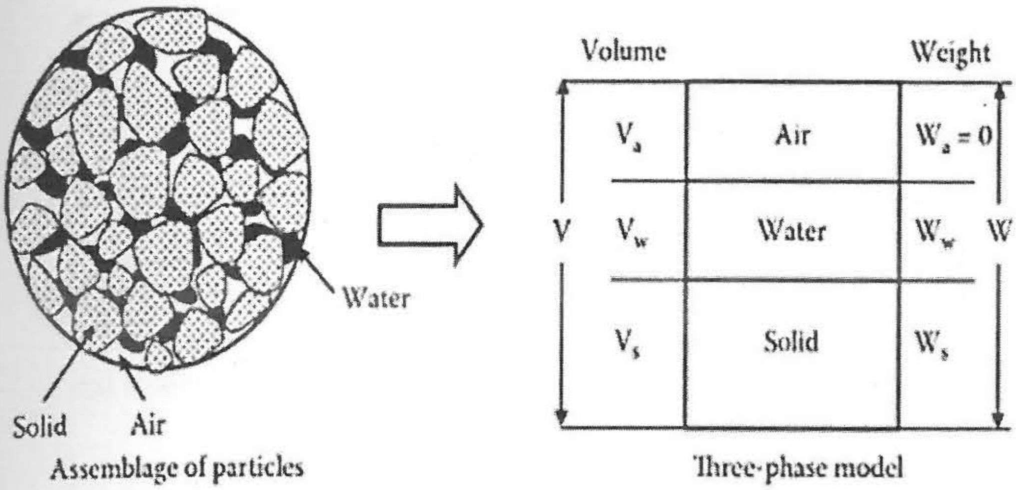

Figure 2.6 Three-phase diagram of soil.

Based on the figure 2.3, the porosity (n) and void ratio (e) can be determined using volume-mass relationship, (Ishibashi & Hazarika, 2011).

$$porosity: n = \frac{v_v}{v} = \frac{v_a + v_w}{v} \tag{2.1}$$

$$voidratio: e = \frac{v_v}{v_s} \tag{2.2}$$

Where, V_v = the volume of void

V_w = The volume of water

V_a = The volume of air

V_s = The volume of solid